



US006855595B2

(12) **United States Patent**
Han et al.

(10) **Patent No.:** **US 6,855,595 B2**
(45) **Date of Patent:** **Feb. 15, 2005**

(54) **METHOD FOR MANUFACTURING A CMOS IMAGE SENSOR HAVING A CAPACITOR'S TOP ELECTRODE IN CONTACT WITH A PHOTO-SENSING ELEMENT**

(75) Inventors: **Jin-Su Han, Ichon-shi (KR); Hoon-Sang Oh, Ichon-shi (KR)**

(73) Assignee: **Hynix Semiconductor Inc. (KR)**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 46 days.

(21) Appl. No.: **10/326,680**

(22) Filed: **Dec. 20, 2002**

(65) **Prior Publication Data**

US 2003/0122169 A1 Jul. 3, 2003

Related U.S. Application Data

(62) Division of application No. 09/742,817, filed on Dec. 19, 2000, now Pat. No. 6,521,924.

(30) **Foreign Application Priority Data**

Dec. 28, 1999 (KR) 1999-63839

(51) **Int. Cl.**⁷ **H01L 21/8242**

(52) **U.S. Cl.** **438/241; 438/210; 438/239; 438/250; 438/381; 438/57; 438/60**

(58) **Field of Search** **438/200, 238-241, 438/250, 210, 381, 393, 57, 60**

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,356,826 A * 10/1994 Natsume 438/238

5,760,458 A * 6/1998 Bergemont et al. 257/588
6,057,572 A 5/2000 Ito et al.
6,103,621 A * 8/2000 Huang 438/652
6,204,524 B1 * 3/2001 Rhodes 257/222
6,255,703 B1 * 7/2001 Hause et al. 257/384
6,333,205 B1 * 12/2001 Rhodes 438/69
6,376,868 B1 * 4/2002 Rhodes 257/215
6,521,924 B2 * 2/2003 Han et al. 257/290

FOREIGN PATENT DOCUMENTS

JP 5-13739 1/1993

* cited by examiner

Primary Examiner—Amir Zarabian

Assistant Examiner—Khanh Duong

(74) *Attorney, Agent, or Firm*—Townsend and Townsend and Crew LLP

(57) **ABSTRACT**

An image sensor includes a plurality of unit pixels for sensing a light beam to generate an image data. Each of the unit pixels includes, a photoelectric element for sensing a light beam incident thereto and generating photoelectric charges, a transistor including a gate dielectric formed adjacent to the photoelectric element and a gate electrode formed on top of the gate dielectric and a capacitor structure including an insulating film formed on a portion of the photoelectric element and a bottom electrode, wherein the insulating film and the gate dielectric are made of a same material and the bottom electrode and the gate electrode are made of a same material.

40 Claims, 11 Drawing Sheets

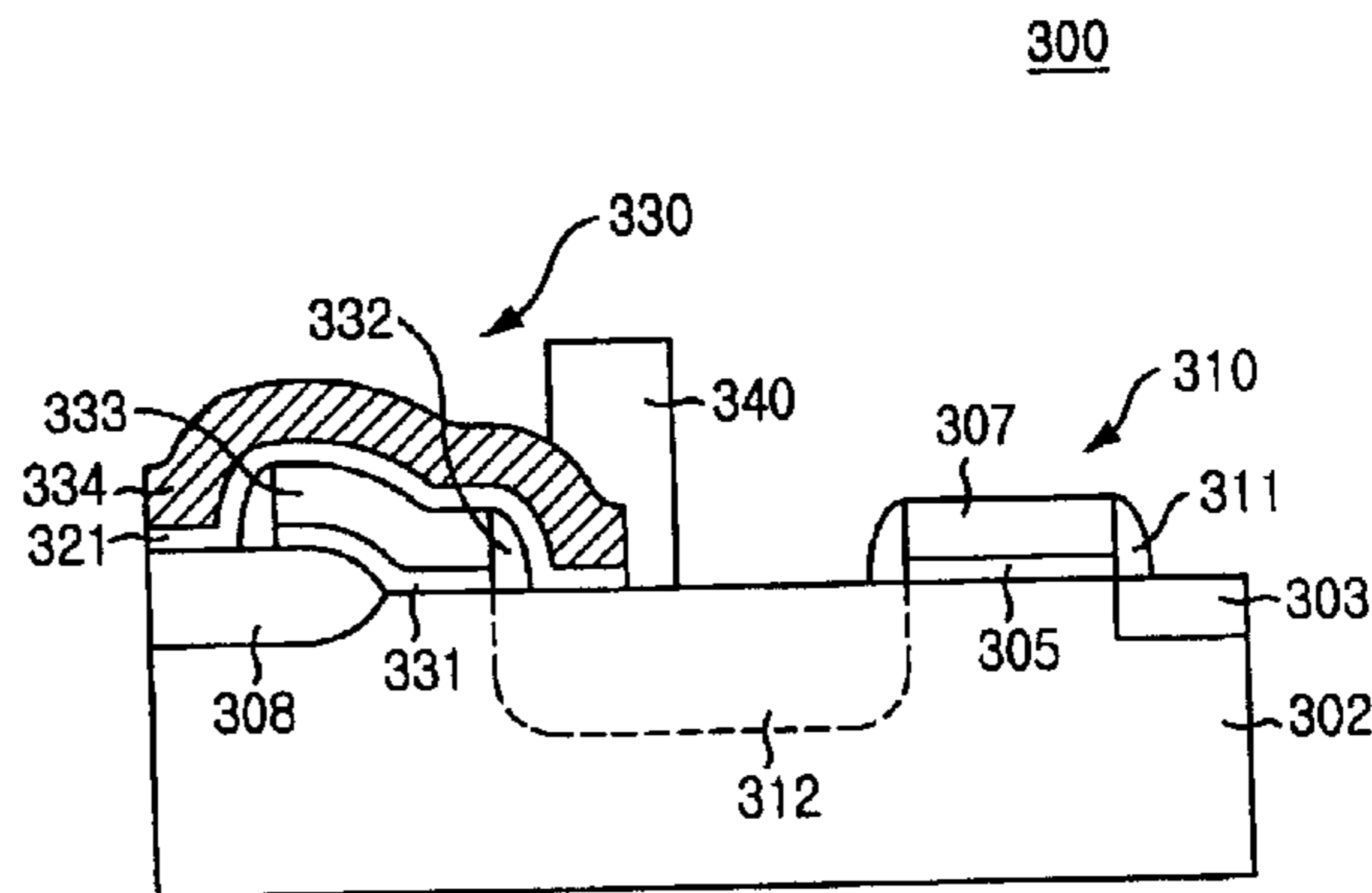
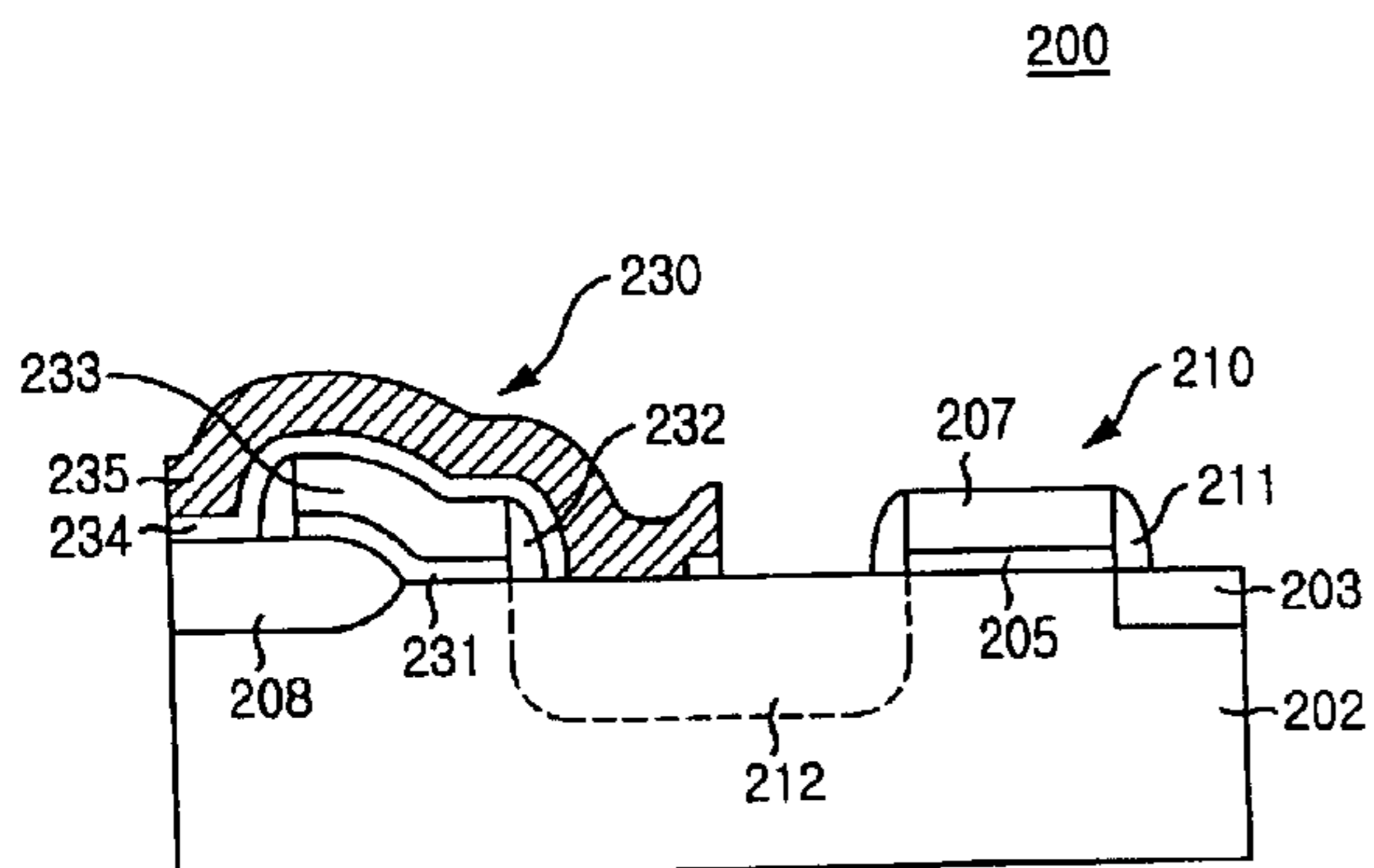


FIG. 1
(PRIOR ART)

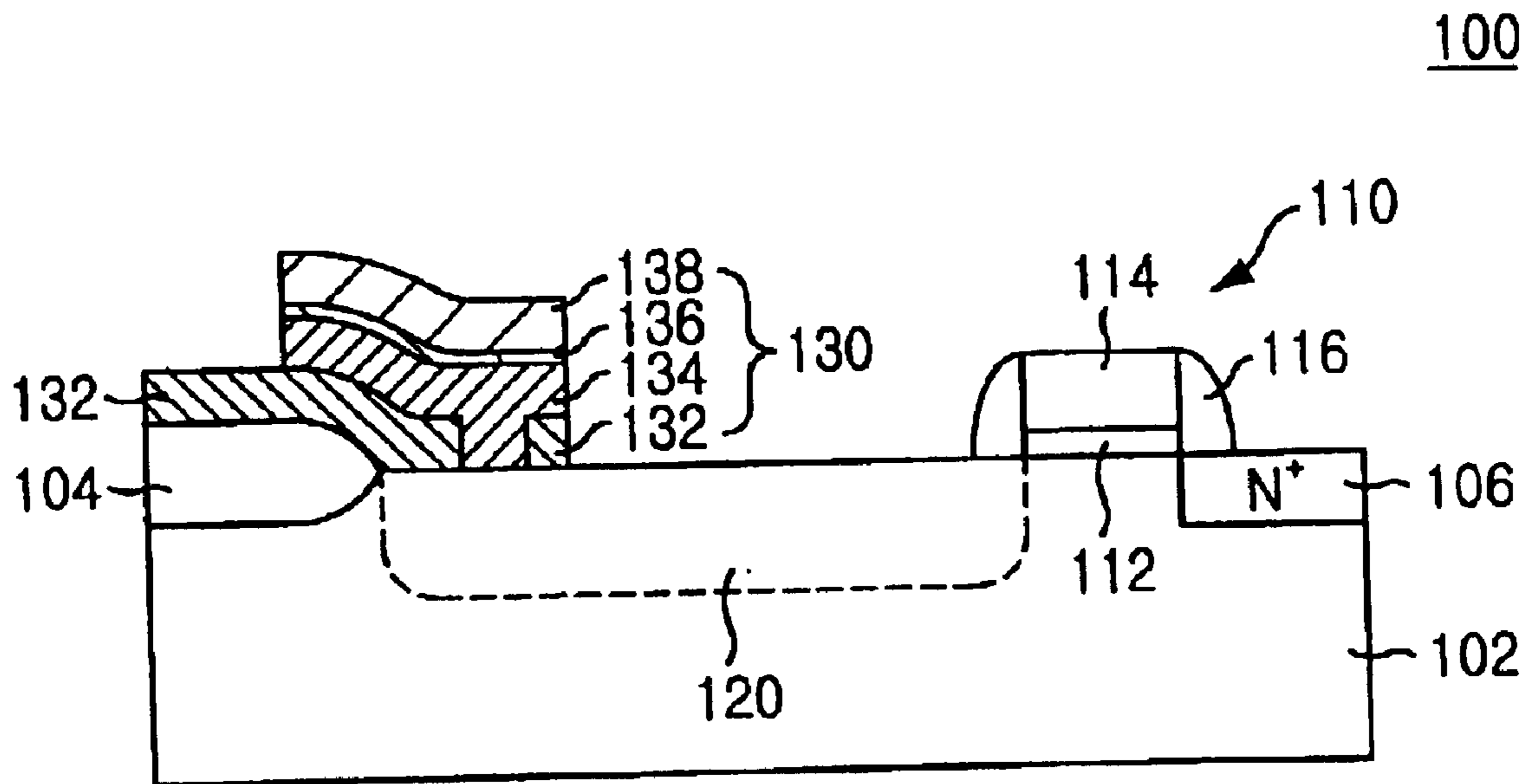


FIG. 2A
(PRIOR ART)

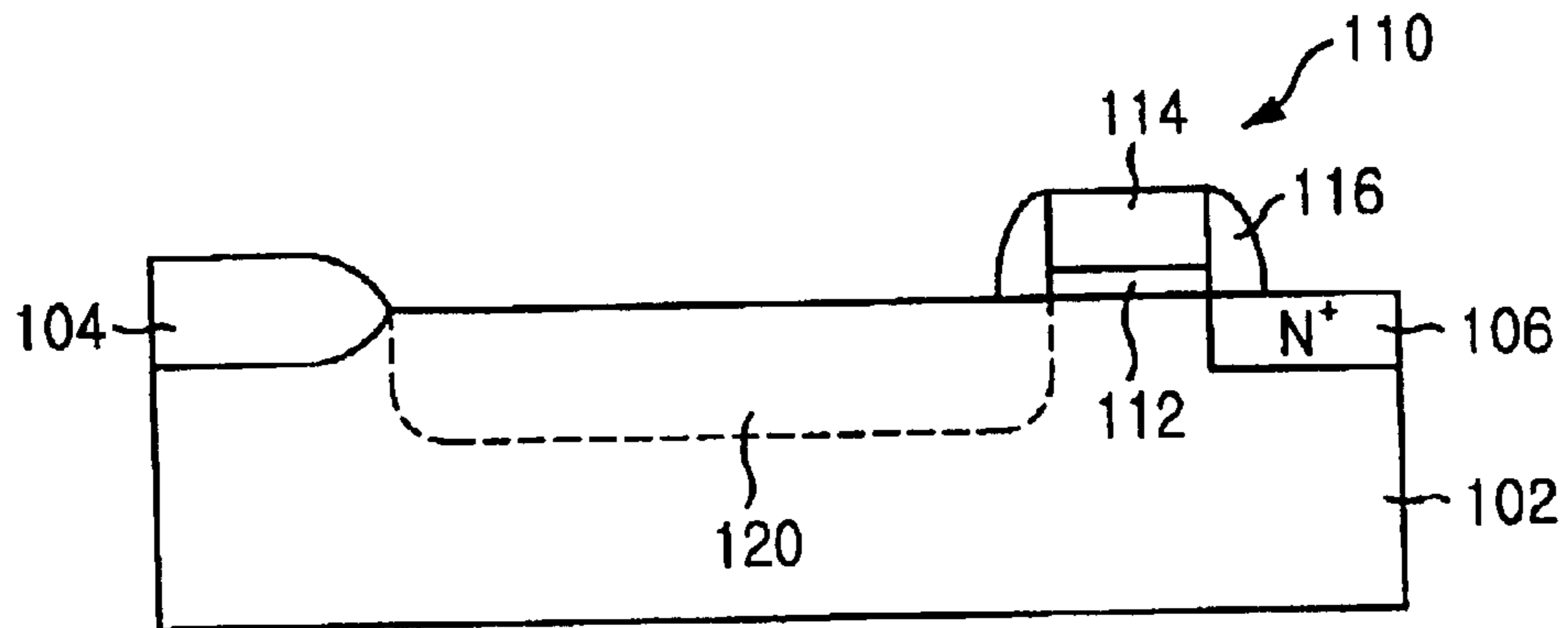


FIG. 2B
(PRIOR ART)

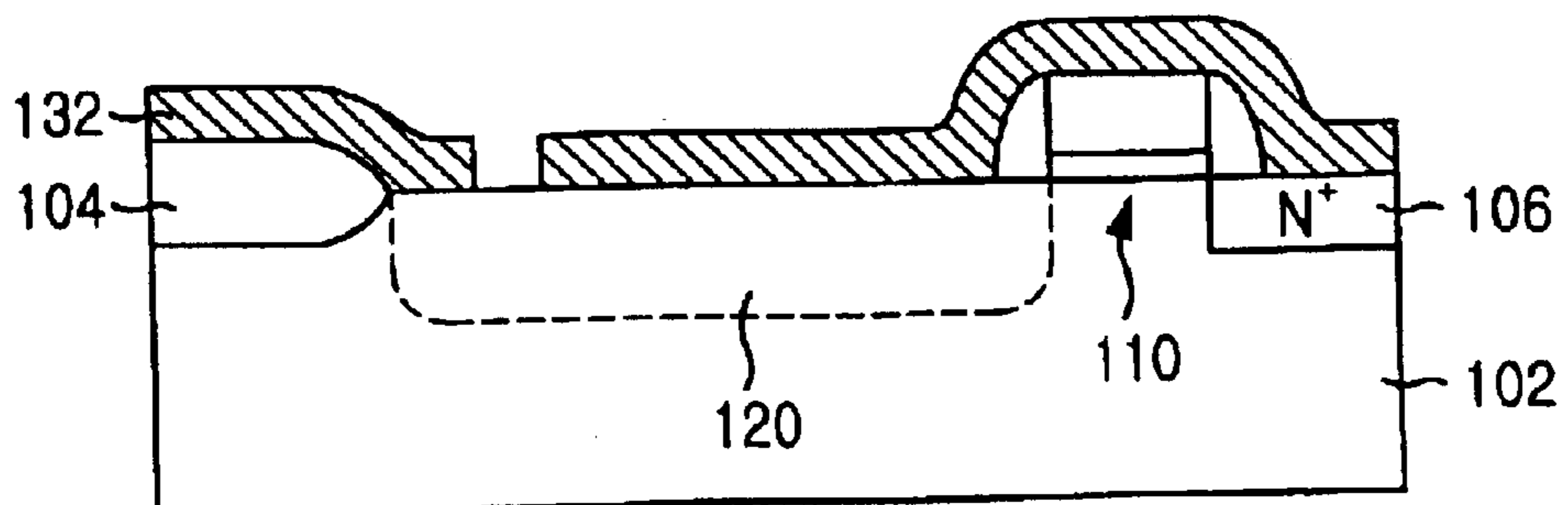


FIG. 2C
(PRIOR ART)

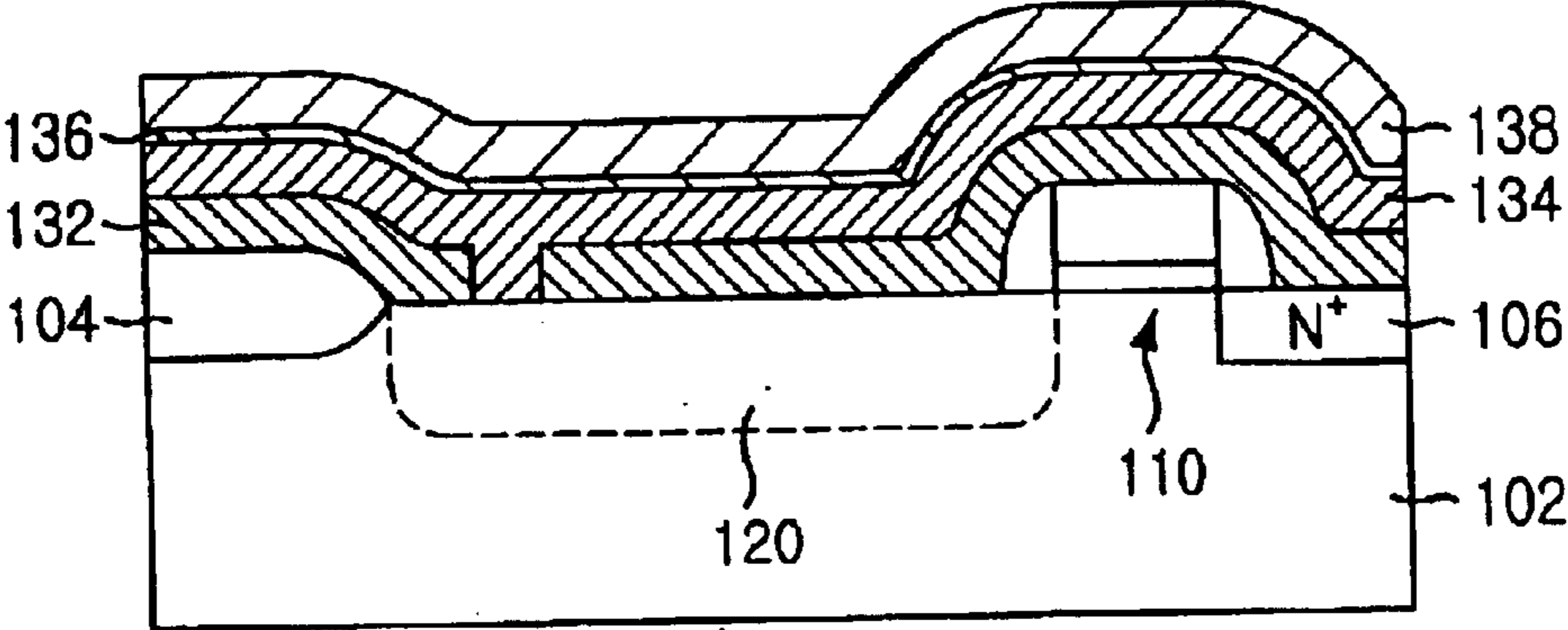


FIG. 2D
(PRIOR ART)

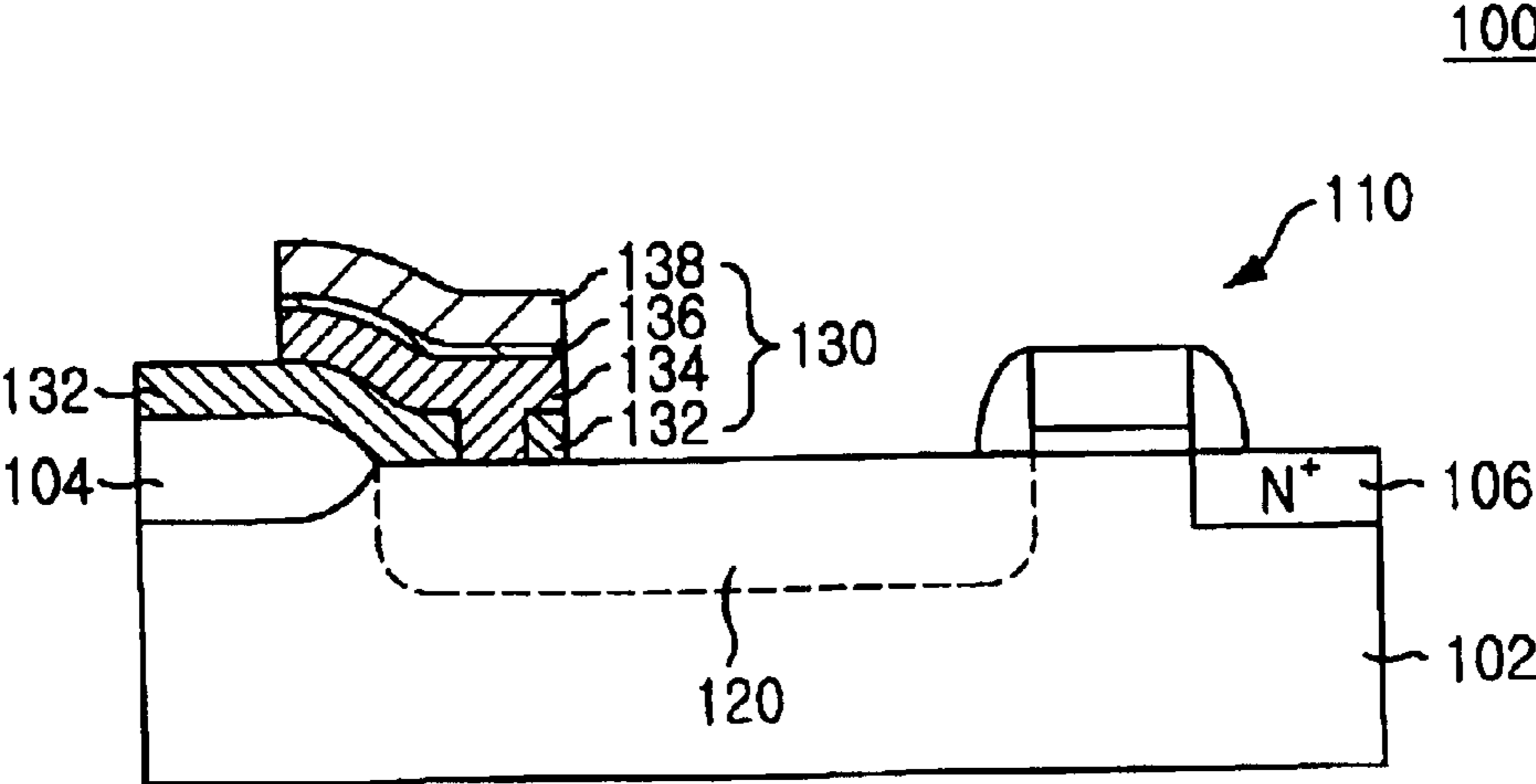


FIG. 3

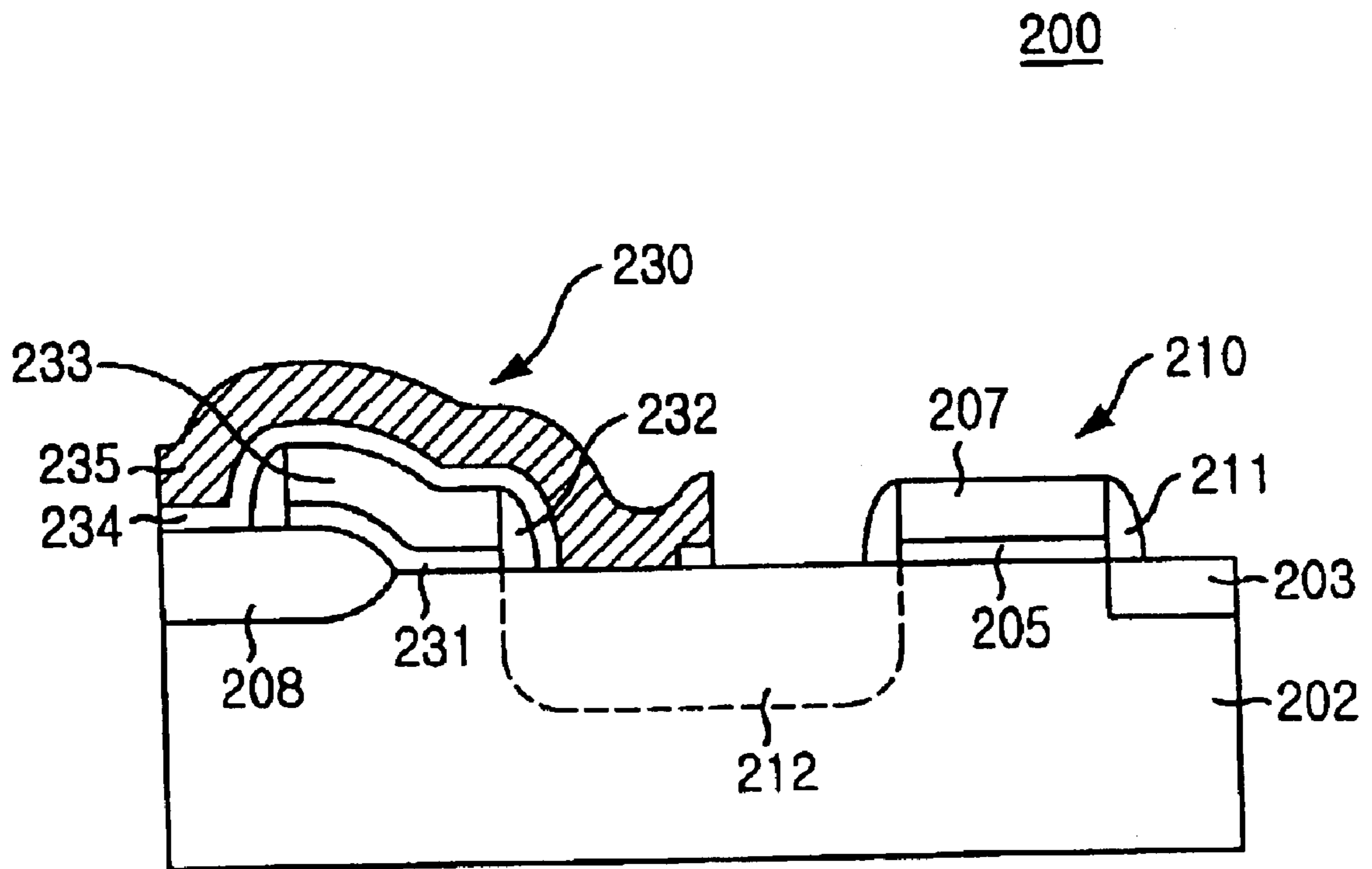


FIG. 4A

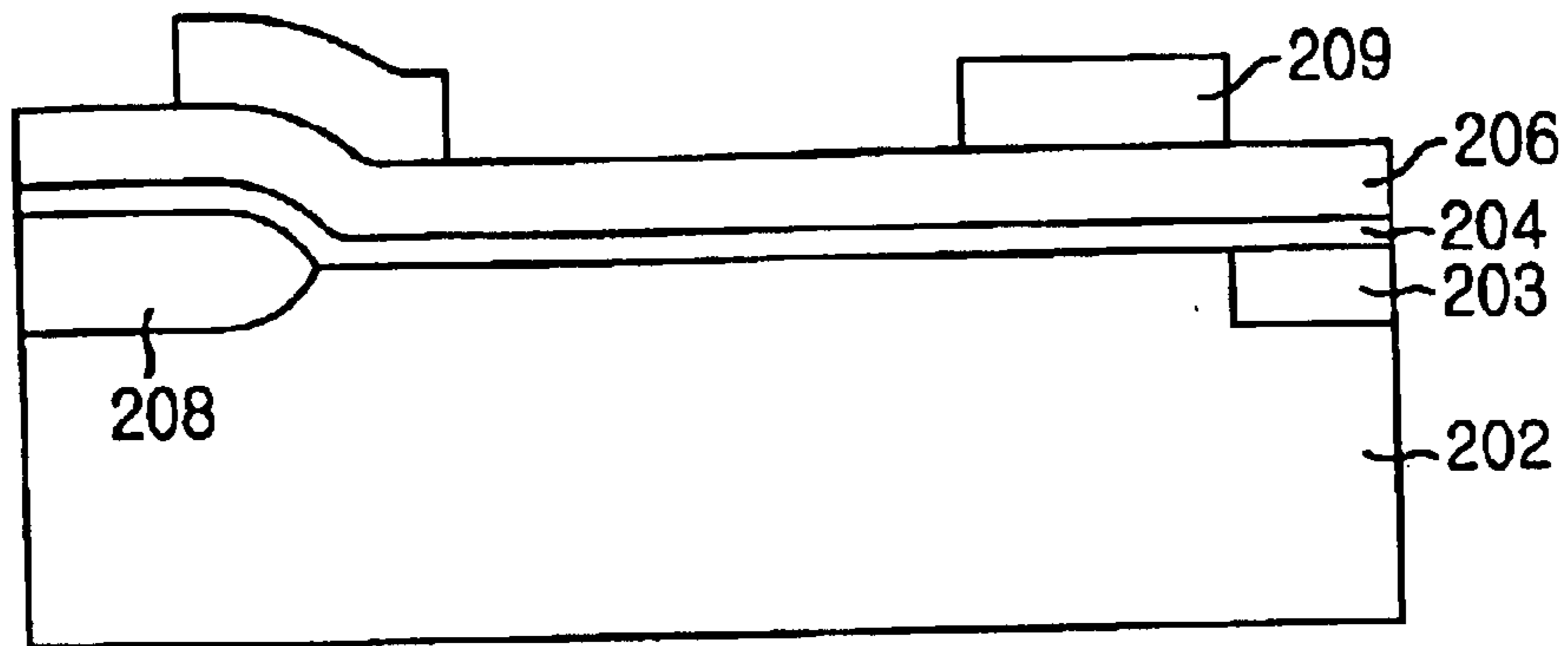


FIG. 4B

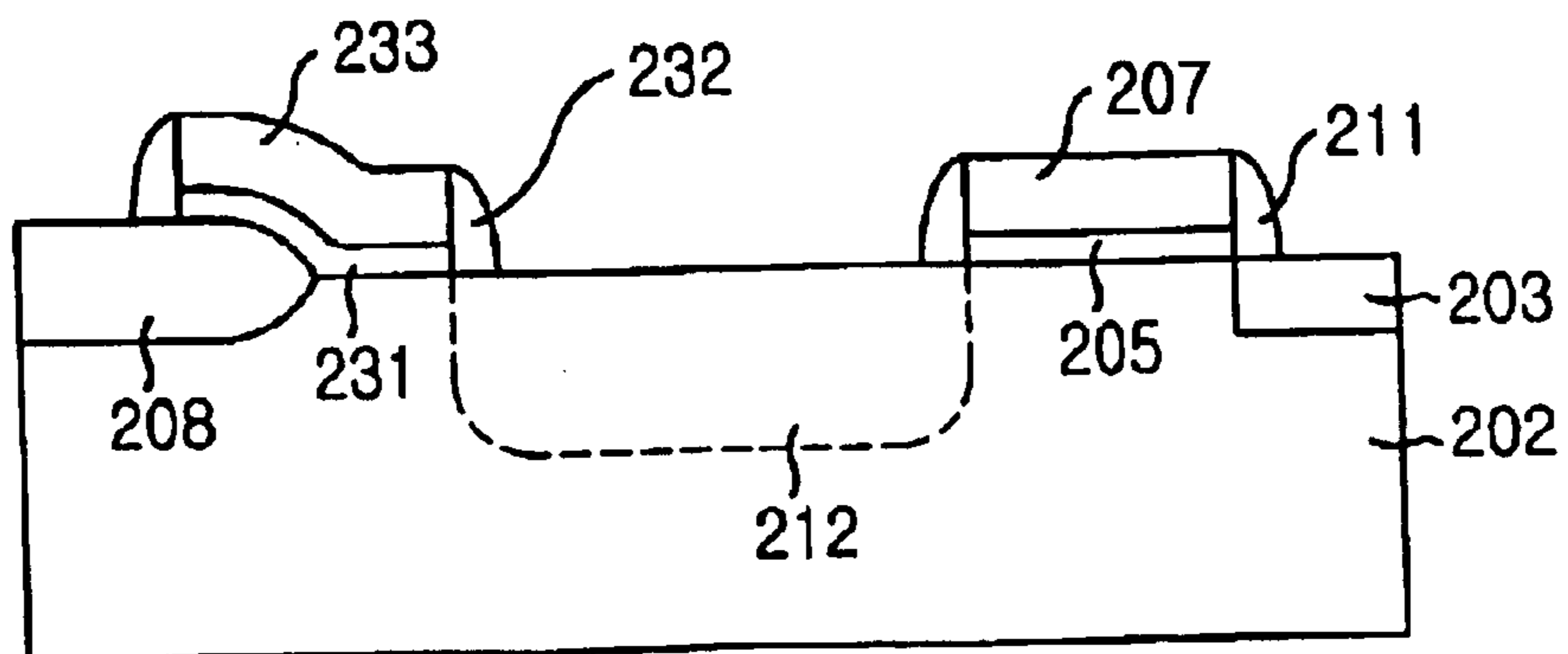


FIG. 4C

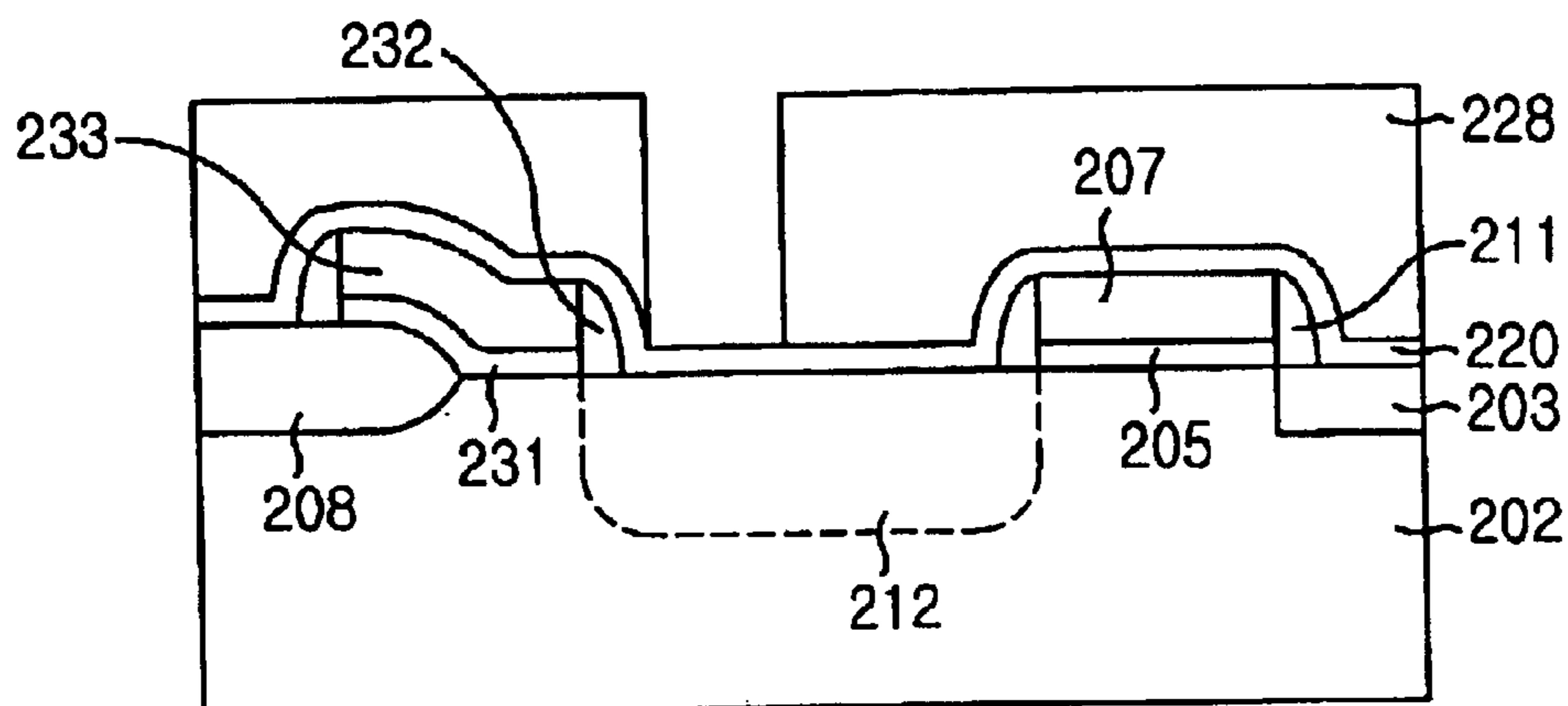


FIG. 4D

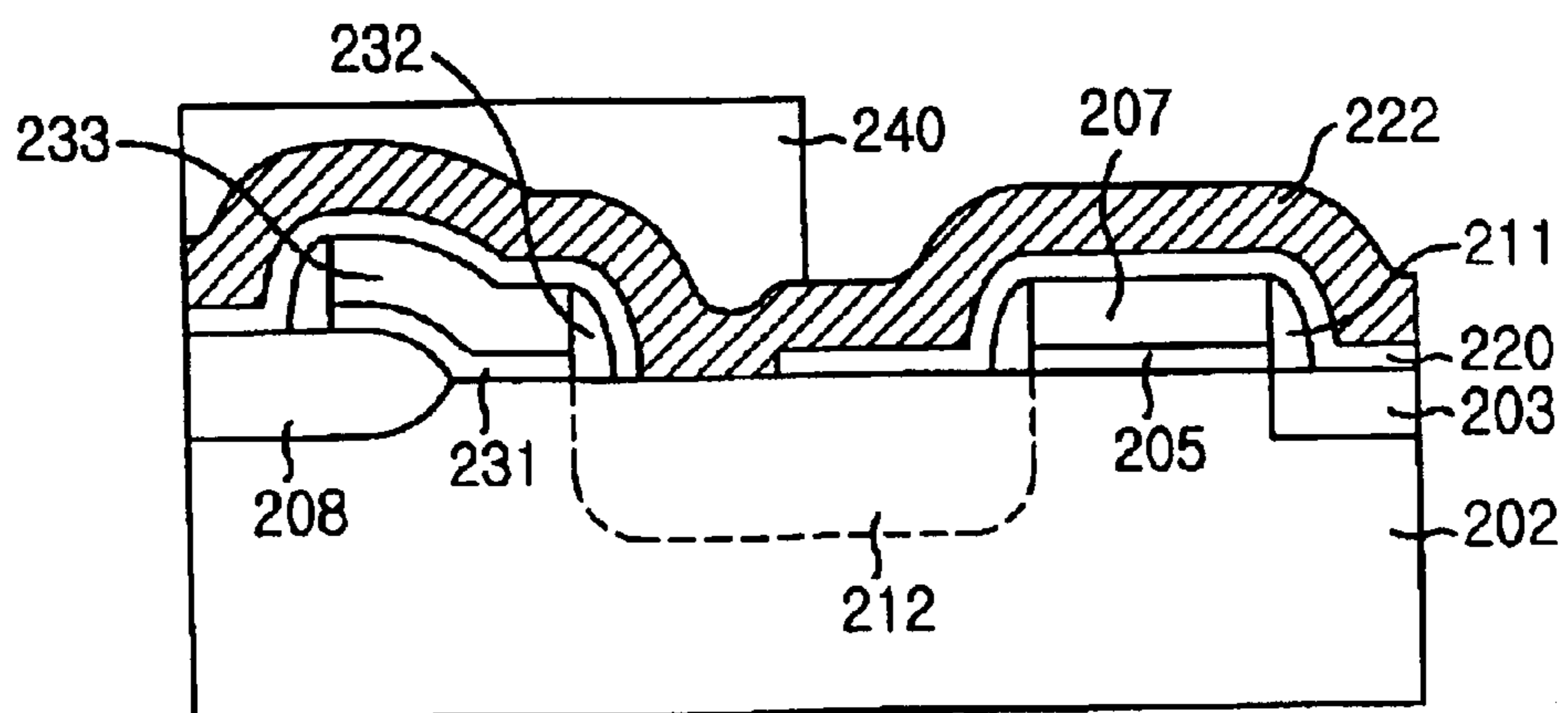


FIG. 4E

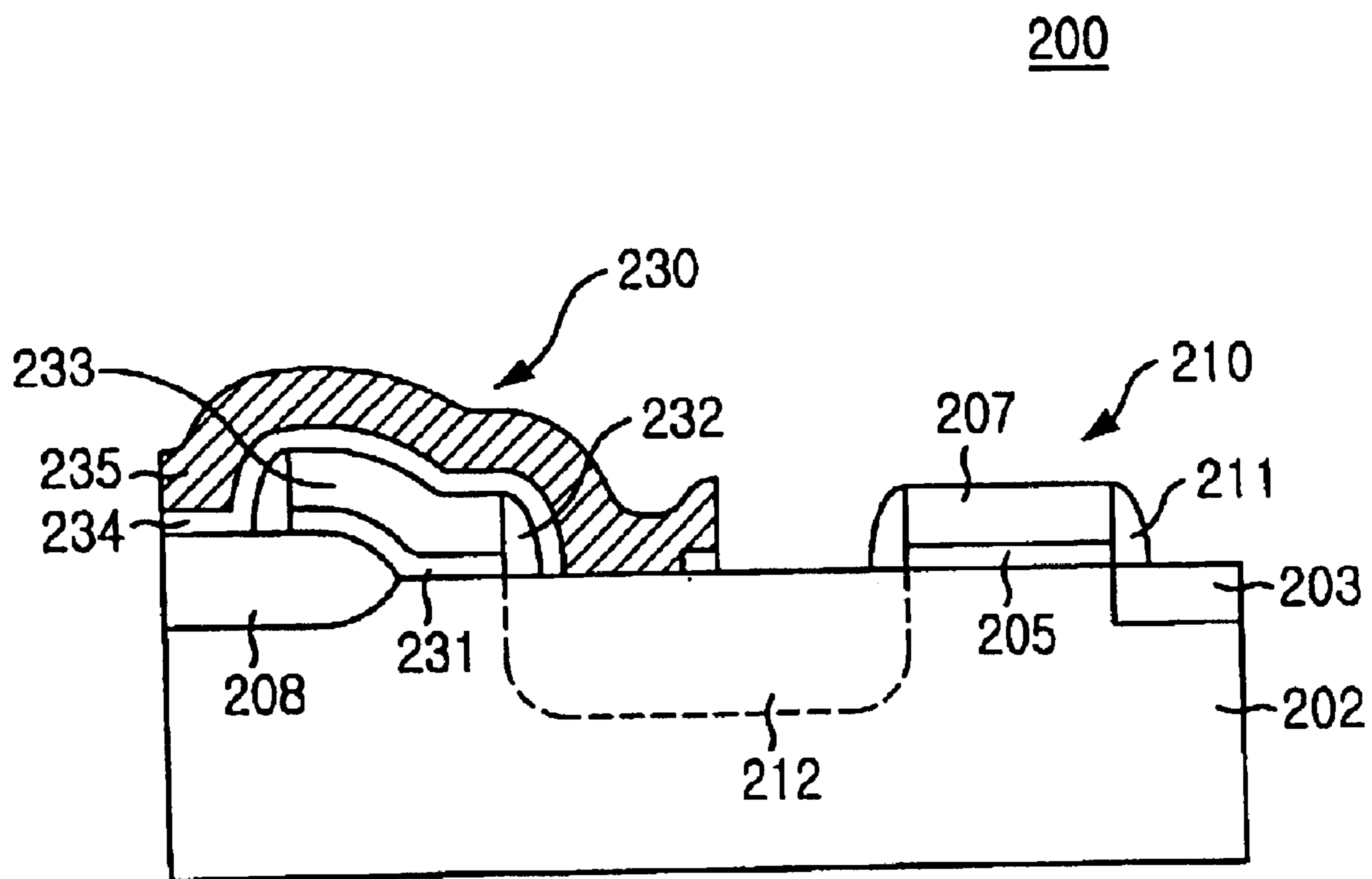


FIG. 5

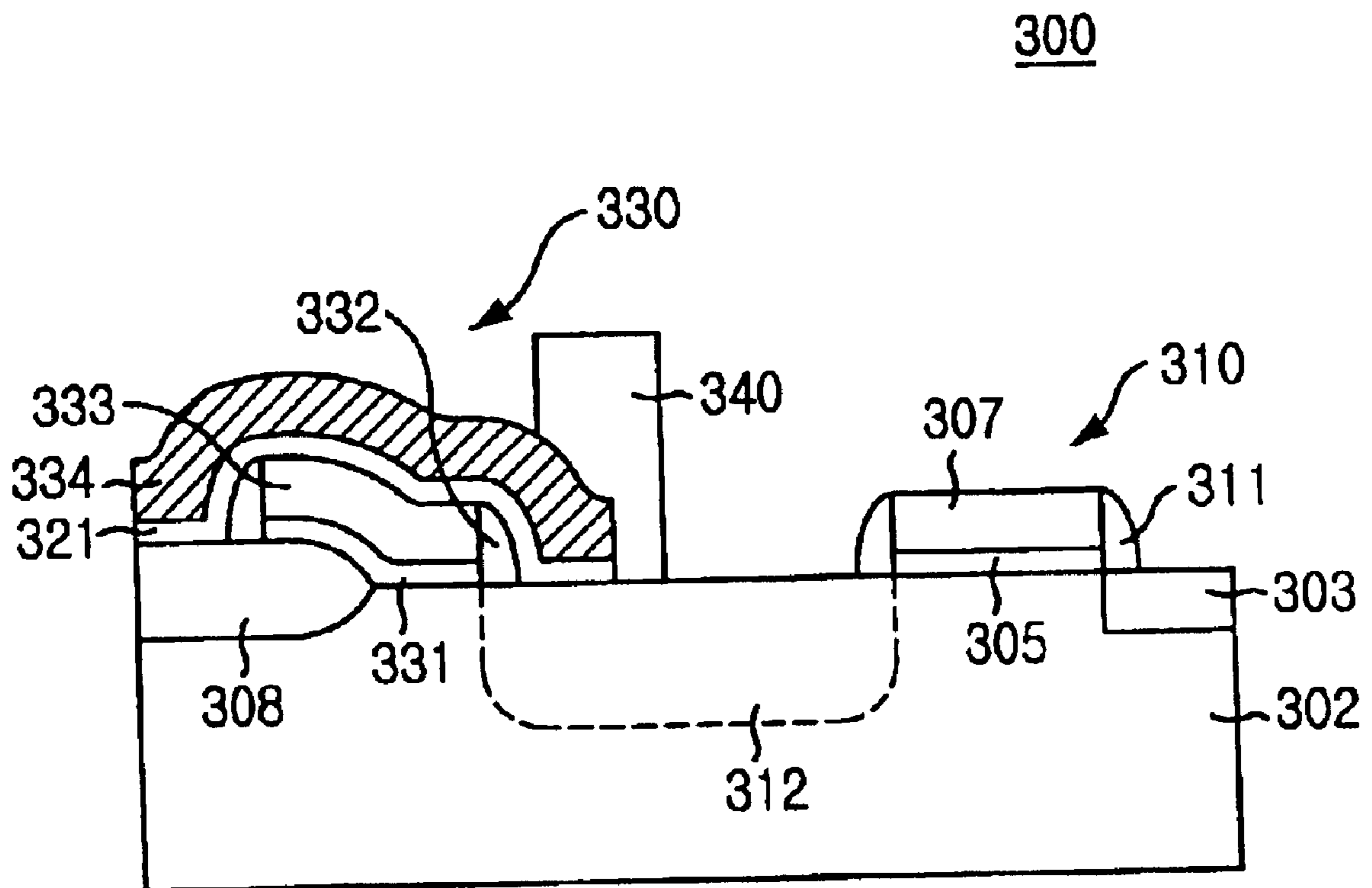


FIG. 6A

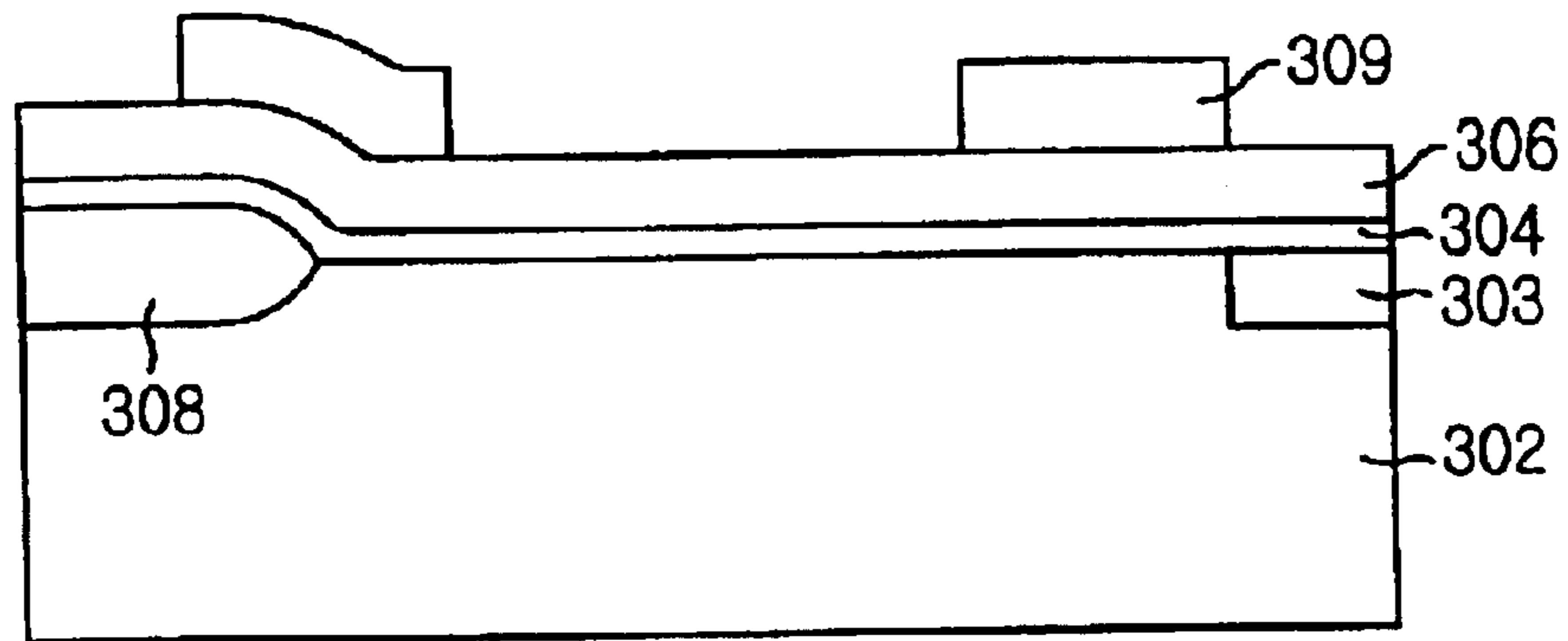


FIG. 6B

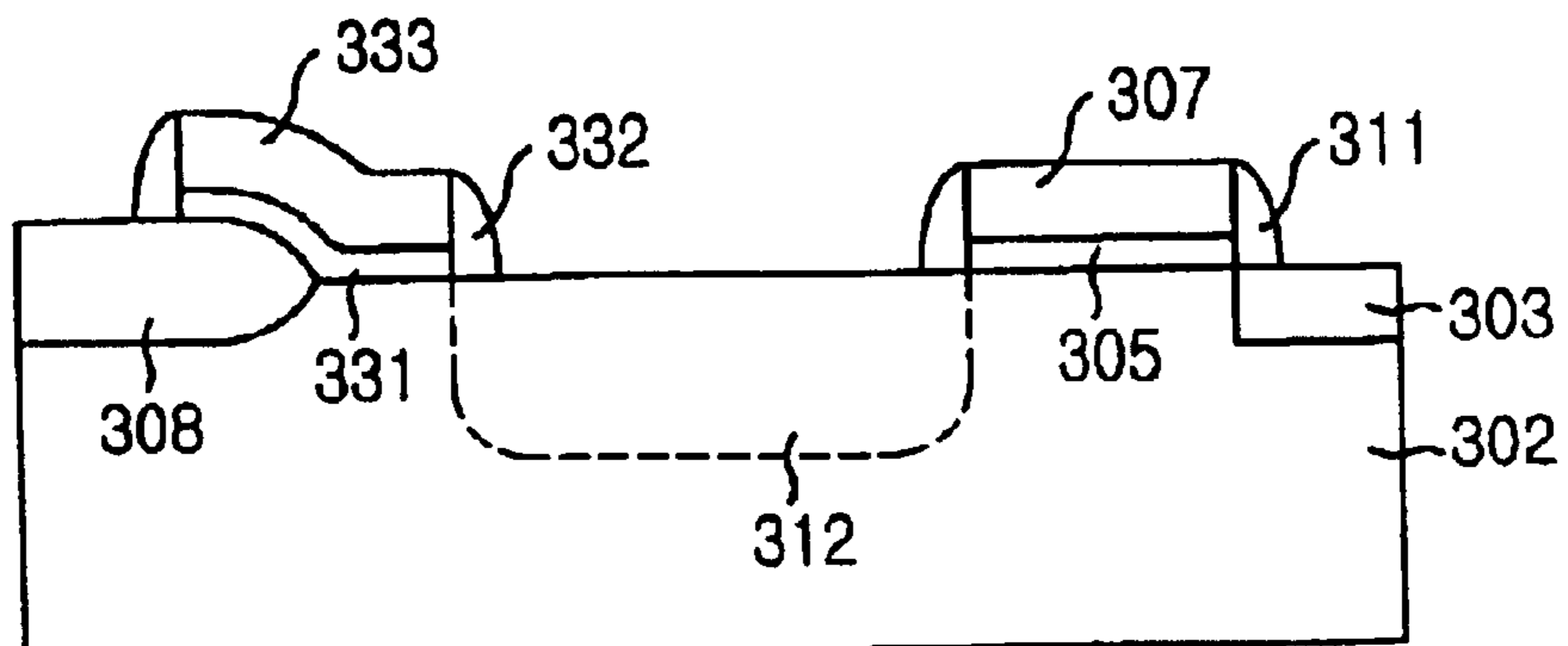


FIG. 6C

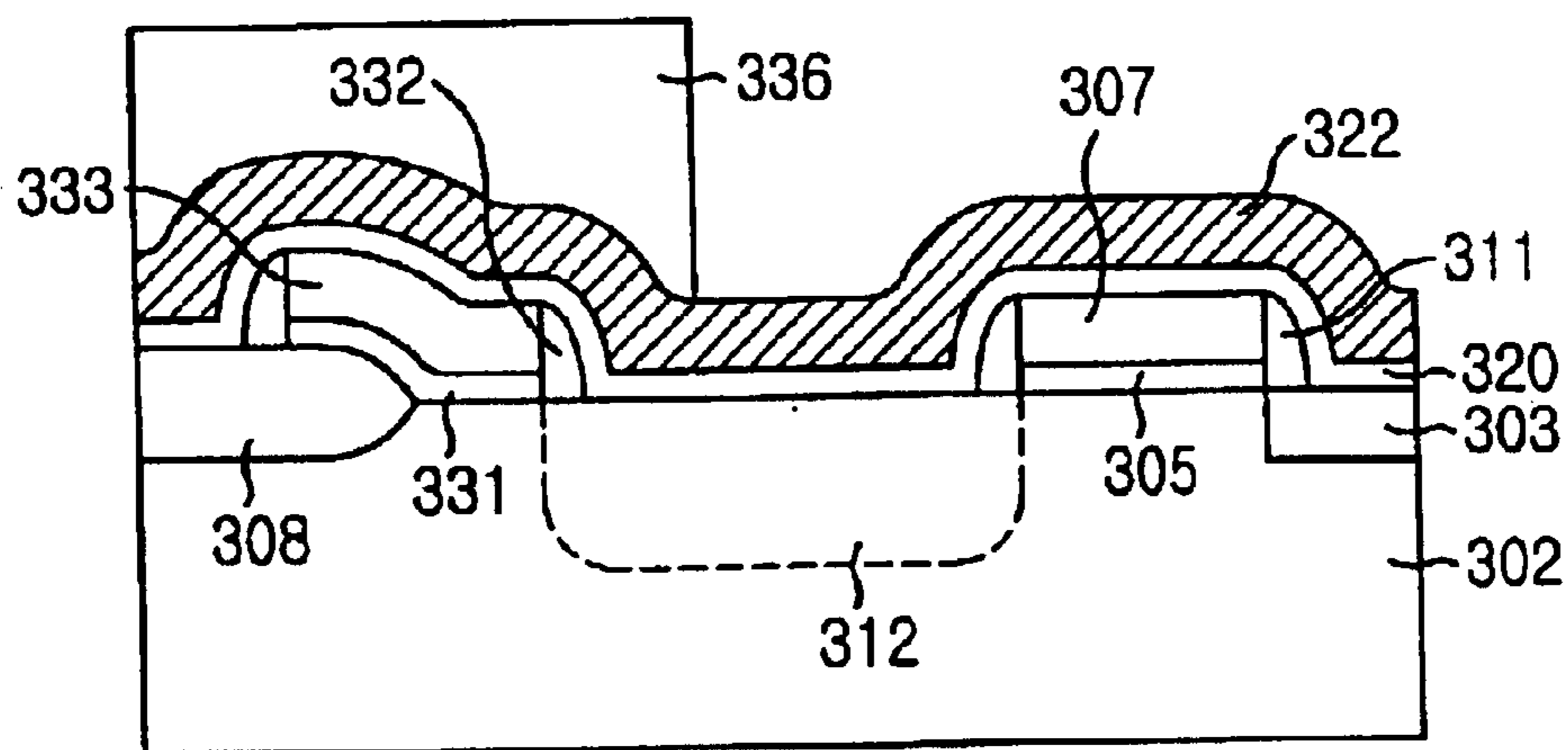


FIG. 6D

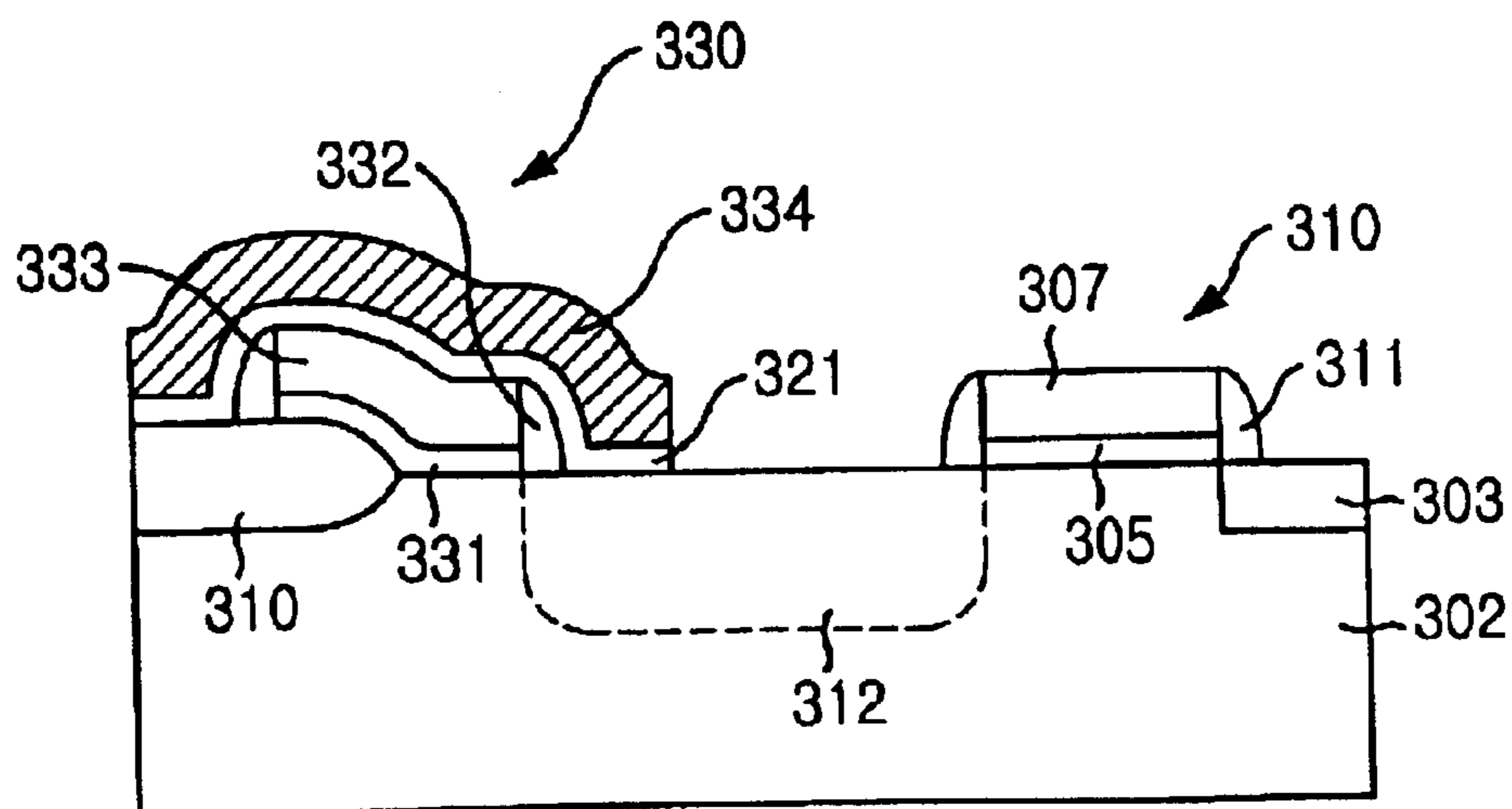
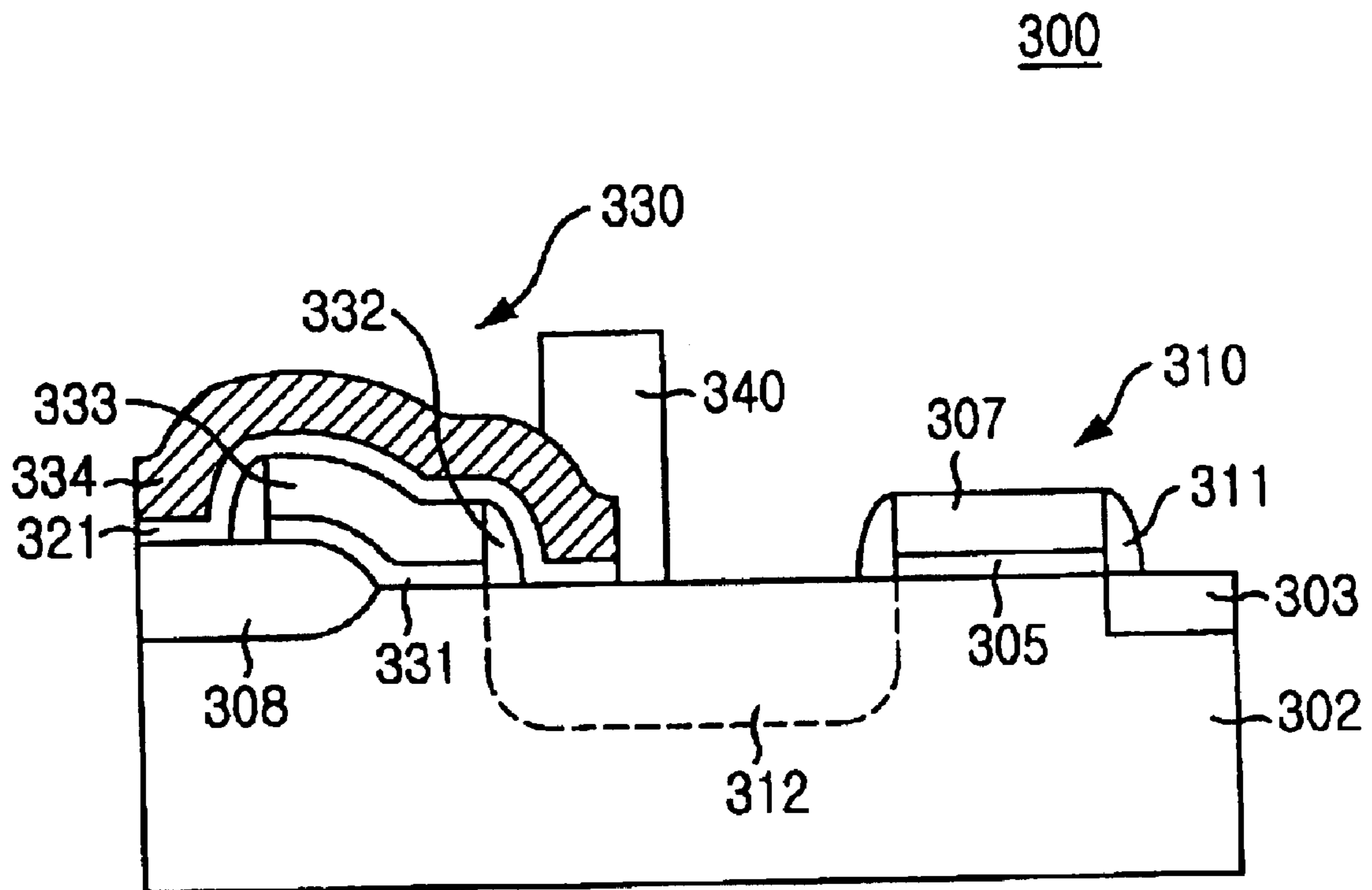


FIG. 6E



**METHOD FOR MANUFACTURING A CMOS
IMAGE SENSOR HAVING A CAPACITOR'S
TOP ELECTRODE IN CONTACT WITH A
PHOTO-SENSING ELEMENT**

FIELD OF THE INVENTION

The present invention relates to an image sensor; and, more particularly, to an image sensor incorporating therein a capacitor structure for improving an optical efficiency of the image sensor.

DESCRIPTION OF THE PRIOR ART

As is well known, an image sensor is a semiconductor device for sensing a light reflected from an object to generate an image data. Especially, an image sensor fabricated by using a complementary metal oxide semiconductor (CMOS) technology is called a CMOS image sensor.

Generally, the CMOS image sensor includes a plurality of unit pixels. Each of the unit pixels also includes a light sensing element and a plurality of transistors. The light-sensing element such as a photodiode senses incident light reflected from an object and accumulates photoelectric charges that are generated due to the incident light. The transistors control a transfer of the photoelectric charges.

In FIG. 1, there is shown a prior art image sensor **100** including: a silicon substrate **102**, a photodiode **120** formed into the silicon substrate **102** for sensing a light beam incident thereto and generating photoelectric charges, a capacitor structure **130** formed on the silicon substrate **102** and the photodiode **120**, a diffusion region **106**, a transfer transistor **110** formed on the photodiode **120**, the diffusion region **106** and an isolation region **104**.

In the image sensor **100**, the transfer transistor **110** is provided with a gate dielectric **112**, a gate electrode **114** and a spacer **116**. The transfer transistor **110** is coupled to a sensing node for transferring the photoelectric charges to the sensing node in response to a transfer control signal. The capacitor structure **130** is provided with an insulating film **132**, a bottom electrode **134**, a capacitor dielectric **136** and a top electrode **138**. In case when the photodiode **120** does not have sufficient capacitance, a certain portion of the photoelectric charges cannot be stored in the photodiode **120**, which will, in turn, leak out into the silicon substrate **102**, thereby decreasing an overall optical efficiency thereof and making noises in the image sensor **100**. These problems can be eliminated by using the capacitor structure **130** which is capable of providing additional capacitances to the photodiode **120**.

In FIGS. 2A to 2D, there are illustrated manufacturing steps involved in manufacturing the conventional image sensor **100**.

The process for manufacturing the conventional image sensor **100** begins with the preparation of an active matrix having a silicon substrate **102**, a transfer transistor structure **110** formed thereon, an isolation region **104** and a photodiode **120** formed into the silicon substrate **102**, as shown in FIG. 2A. An insulating layer **132**, e.g., made of SiO_x, is formed over the entire surface by using a chemical vapor deposition (CVD) technique. The photodiode **120** is capable of converting a light beam incident thereto into photoelectric charges. The transfer transistor **110** includes a gate oxide **112**, a gate electrode **114** and a spacer **116**. The transfer transistor **110** is coupled to a sensing node **106** for transferring the photoelectric charges to the sensing node **106** in

response to a transfer control signal. The sensing node **106** can be connected to a transistor such as a reset transistor or an amplification transistor not shown for the sake of simplicity.

Referring to FIG. 23, an insulating layer **132**, e.g., made of silicon oxide (SiO₂), is formed on top of the active matrix by using a method such as CVD. Thereafter, the insulating layer **132** is patterned into a first predetermined configuration to form a contact hole.

In a next step, a bottom electrode layer **134**, a capacitor dielectric layer **136** and a top electrode layer **138** are formed on the insulating layer **132**, successively, as shown in FIG. 2C.

Finally, the top electrode layer **138**, the capacitor dielectric layer **136** and the bottom electrode layer **134** are patterned into a second predetermined configuration, thereby obtaining a capacitor structure **130**.

One of the major shortcomings of the above-described image sensor **100** is that it has complex manufacturing steps to form the capacitor structure **130** on the photodiode **120**.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an image sensor incorporating therein a capacitor structure for improving an optical efficiency thereof.

It is another object of the present invention to provide a method for manufacturing an image sensor incorporating therein a capacitor for improving an optical efficiency hereof.

In accordance with an aspect of the present invention, there is provided an image sensor provided with a plurality of unit pixels, each unit pixel comprising: a photoelectric element for sensing a light beam incident thereto and generating photoelectric charges; a transistor including a gate dielectric formed adjacent to the photoelectric element and a gate electrode formed on top of the gate dielectric; and a capacitor structure including an insulating film formed on a portion of the photoelectric element and a bottom electrode, wherein the insulating film and the gate dielectric are made of a same material and the bottom electrode and the gate electrode are made of a same material.

In accordance with another aspect of the present invention, there is provided a method for manufacturing an image sensor, the method comprising the steps of: a) preparing a silicon substrate; b) forming a first dielectric layer and a first conductive layer, successively; c) patterning the first dielectric layer and the first conductive layer to obtain an insulating film and a bottom electrode of a capacitor structure and a gate dielectric and a gate electrode of a transistor, simultaneously; d) implanting a first type of dopants into a portion of the silicon substrate which is not covered with the insulating film and the gate dielectric and placed therebetween, thereby forming a photoelectric element; e) forming a second dielectric layer; f) removing a portion of the second dielectric layer which is located on top of the photoelectric element, thereby forming a contact hole; g) forming a second conductive layer on top of the second dielectric layer and the contact hole; and h) removing portions of the second conductive layer and the second dielectric layer which are placed on top of the gate electrode and the remaining portion of the photoelectric element.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and aspects of the invention will become apparent from the following description of the embodiments with reference to the accompanying drawings, in which:

FIG. 1 is a cross-sectional view showing a prior art CMOS image sensor;

FIGS. 2A to 2D provide cross-sectional views presenting a prior art method for manufacture of the CMOS image sensor shown in FIG. 1;

FIG. 3 illustrates a cross-sectional view representing a CMOS image sensor in accordance with a first preferred embodiment of the present invention;

FIGS. 4A to 4E are schematic cross-sectional views illustrating a method for the manufacture of a CMOS image sensor shown in FIG. 3;

FIG. 5 is a cross-sectional view setting forth a CMOS imager sensor in accordance with a second preferred embodiment of the present invention; and

FIGS. 6A to 6E show schematic cross-sectional views depicting a method for the manufacture of a CMOS image sensor in accordance with a second preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

There are provided in FIGS. 3, 4A to 4E, 5, and 6A to 6E a cross-sectional views of CMOS image sensors 200 and 300, and cross-sectional views setting forth methods for the manufacture thereof in accordance with embodiments of the present invention.

In FIG. 3, there is provided a cross sectional view of the inventive image sensor 200 comprising a silicon substrate 202, a photo-sensing element 212, an isolation region 208, a transfer transistor 210 and a capacitor structure 230. The photo-sensing element 212 includes an N-type conducting region that is formed in the silicon substrate 202. The conducting region forms a P-N junction with the P-type material of the silicon substrate 202 to collect photoelectric charges. Therefore, the photo-sensing element 212 is capable of converting a light beam impinging thereon into photoelectric charges. The transfer transistor 210 includes a gate oxide 205, a gate electrode 207 and a spacer 211. The transfer transistor 210 is coupled to a sensing node 203. The sensing node 203 is implanted with N+ dopants for transferring the photoelectric charges to the sensing node 203 in response to a transfer control signal. Although the other devices, e.g., a reset transistor or an amplification transistor, are not shown for the sake of the simplicity, the sensing node can be connected to the other devices.

The capacitor structure 230 includes an insulating film 231, a bottom electrode 233, a spacer 232, a capacitor dielectric 234 and a top electrode 235. In the preferred embodiment, the insulating film 231 is made of a material, e.g., SiO_x or the like, used for the gate oxide 205. The bottom electrode 233 is also made of a material, e.g., doped polysilicon or the like, used for the gate electrode 207. It is possible that the gate oxide 205 and the insulating film 231 can be made of a high K dielectric material such as Ta₂O₅.

In FIGS. 4A to 4E, there are illustrated manufacturing steps involved in manufacturing the image sensor 200 in accordance with a first preferred embodiment of the present invention.

The process for manufacturing the image sensor 200 begins with the preparation of a silicon substrate 202 provided with an isolation region 208 and a sensing node 203 formed therein. Thereafter, a first dielectric layer 204, e.g., made of SiO₂, is formed on the silicon substrate 202 by using a method such as a chemical vapor deposition (CVD). A first conductive layer 206, e.g., made of doped polysilicon,

formed on top of the first dielectric layer 204 by using a method such as CVD. In order to define a conducting region, a transfer transistor and a capacitor structure, a first photoresist layer is formed on top of the first conductive layer 206 and patterned into a predetermined configuration, thereby obtaining a patterned photoresist layer 209, as shown in FIG. 4A. It is preferable that the silicon substrate 202 is prepared with forming a P-type epitaxial layer on a P-type substrate, wherein an impurity concentration of the D-type epitaxial layer is lower than that of the P-type substrate.

In an ensuing step, portions of the first conductive layer 206 and the first dielectric layer 204, which are not covered with the patterned photoresist layer 209, are removed by using an etching process, thereby obtaining an insulating film 231, a bottom electrode 233, a gate dielectric 205 and a gate electrode 207, as shown in FIG. 4B. Optionally, a spacer 211 can be formed on sides of the gate dielectric 205 and the gate electrode 207. A spacer 232 also can be formed on sides of the insulating film 231 and the bottom electrode 233. Thereafter, first N⁺ dopants are implanted into a sending node 203 and second N⁺ dopants are implanted into the conducting region 212, wherein the impurity of the second N⁺ dopants is deeper than that of the first N⁺ dopants.

In a next step, a second dielectric layer 220 is formed on top of the bottom electrode 233 and the gate electrode 207. A second photoresist layer is formed on top of the second dielectric layer 220 by using a method such as a spin coating and patterned into a preset configuration 228 to define a contact hole, as shown in FIG. 4C. Thereafter, the second dielectric layer 220 is etched by using a chemical, thereby exposing a portion of the conducting region 212.

In a following step, a second conductive layer 222, e.g., made of doped polysilicon, is formed in the contact hole and formed on top of the second dielectric layer 220. And then, a third photoresist layer is formed on top of the second conductive layer 222 and patterned into a certain configuration 240 to define a capacitor structure, as shown in FIG. 4D.

Thereafter, portions of the second conductive layer 222 and the second dielectric layer 220 are removed by using a method such as a chemical etching, thereby obtaining the capacitor structure 230, as shown in FIG. 4E.

In comparison with the prior art, the present invention can reduce the steps of the manufacturing the image sensor 200. This is achieved by forming elements, e.g., the insulating film 231, of the capacitor structure 230 and elements, e.g., the gate dielectric 205, of the transfer transistor 210 in the same process.

Alternatively, in FIG. 5, there is provided a cross sectional view of an image sensor 300 in accordance with a second preferred embodiment of the present invention. The image sensor 300 comprises a silicon substrate 302, a photo-sensing element 312, an isolation region 308, a transfer transistor 310 and a capacitor structure 330.

The inventive image sensor 300 is similar to the image sensor 200 shown in FIG. 3 except that the top electrode 334 does not directly contact to the photo-sensing element 312. In the second preferred embodiment, the top electrode 334 can be electrically connected to the photo-sensing element 312 through a conducting member 340.

In FIGS. 6A to 6E, there are illustrated manufacturing steps involved in manufacturing the image sensor 300 in accordance with the second preferred embodiment of the present invention.

The process for manufacturing the image sensor 300 begins with the preparation of a silicon substrate 302 pro-

5

vided with an isolation region **308** and a sensing node **303** formed therein. Thereafter, a first dielectric layer **304**, e.g., made of SiO_2 , is formed on the silicon substrate **302** by using a method such as a chemical vapor deposition (CVD). A first conductive layer **306**, e.g., made of doped polysilicon, formed on top of the first dielectric layer **304** by using a method such as CVD. In order to define a conducting region, a transfer transistor and a capacitor structure, a first photoresist layer is formed on top of the first conductive layer **306** and patterned into a predetermined configuration, thereby obtaining a patterned photoresist layer **309**, as shown in FIG. **6A**. It is preferable that the silicon substrate **302** is prepared with forming a P-type epitaxial layer on a P-type substrate, wherein an impurity concentration of the P-type epitaxial layer is lower than that of the P-type substrate.

In an ensuing step, portions of the first conductive layer **306** and the first dielectric layer **304**, which are not covered with the patterned photoresist layer **309**, are removed by using an etching process, thereby obtaining an insulating film **331**, a bottom electrode **333**, a gate dielectric **305** and a gate electrode **307**, as shown in FIG. **6B**. Optionally, a spacer **311** can be formed on sides of the gate dielectric **305** and the gate electrode **307**. A spacer **332** also can be formed on sides of the insulating film **331** and the bottom electrode **333**. Thereafter, first N^+ dopants are implanted into a sensing node **303** and second N^+ dopants are implanted into the conducting region **312**, wherein the impurity of the second N^+ dopants is deeper than that of the first N^+ dopants.

In a next step, a second dielectric layer **320** is formed on top of the bottom electrode **333** and the gate electrode **307**. A second conductive layer **322**, e.g., made of doped polysilicon, is formed on the second dielectric layer **320**, successively. And then, a second photoresist layer is formed on top of the second conductive layer **322** and patterned into a certain configuration **336** to define a capacitor structure, as shown in FIG. **6C**.

Thereafter, portions of the second conductive layer **322** and the second dielectric layer **320**, which are not covered with the certain configuration **336** of the second photoresist layer, are removed by using a method such as a chemical etching, thereby obtaining the capacitor structure **330**, as shown in FIG. **6D**.

Finally, a conductive member **340** is formed on top of the photo-sensing element **312** with extending over the top electrode **334** of the capacitor structure **330** in such a way that the photo-sensing element **312** is electrically connected to the top electrode **334**.

While the present invention has been described with respect to the particular embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the scope of the invention as defined in the following claims.

What is claimed is:

1. A method for manufacturing an image sensor, the method comprising:

- a) forming a photo-sensing element in a semiconductor substrate;
- b) forming a first dielectric layer on top of the semiconductor substrate;
- c) forming a first conductive layer on top of the first dielectric layer;
- d) patterning, substantially simultaneously, the first dielectric layer and the first conductive layer to form an insulating film and a bottom electrode of a capacitor structure and a gate dielectric and a gate electrode of a transfer transistor;

6

e) forming successively a second dielectric layer and a second conductive layer over the semiconductor substrate; and

f) removing portions of the second conductive layer and the second dielectric layer that overlie the photoelectric element and overlie the gate dielectric to form a capacitor dielectric and a top electrode of the capacitor structure; wherein a portion of the top electrode is in contact with the photo-sensing element.

2. The method of claim **1**, wherein the step c) includes:

c1) patterning the first dielectric layer into a predetermined configuration to form the insulating film and the gate dielectric, substantially simultaneously; and

c2) patterning the first conductive layer into the predetermined configuration to form the bottom electrode and the gate electrode, substantially simultaneously.

3. The method of claim **1** further comprising:

g) implanting dopants of a first type into an exposed portion of the semiconductor substrate that is between the insulating film and the gate dielectric to form the photo-sensing element.

4. The method of claim **3** further comprising implanting dopants of a second type into a portion of the semiconductor substrate adjacent the gate electrode.

5. The method of claim **1**, wherein the gate dielectric is semiconductor oxide (SiO_x).

6. The method of claim **1**, wherein the gate dielectric is tantalum oxide (Ta_2O_5).

7. The method of claim **1**, wherein the insulating film and the gate dielectric are formed of the same type of material.

8. The method of claim **1**, wherein the gate electrode and the bottom electrode are formed of the same type of material.

9. The method of claim **8**, wherein the material is doped polysilicon.

10. A method for manufacturing an image sensor, the method comprising:

forming a photo-sensing element in a semiconductor substrate;

forming a capacitor structure on the semiconductor substrate, wherein forming the capacitor structure includes:

forming an insulating film on a surface of the semiconductor substrate adjacent the photo-sensing element,

forming a bottom electrode on top of the insulating film,

forming a capacitor dielectric layer on top of the bottom electrode; and

forming a top electrode on top of the capacitor dielectric layer and in contact with the photo-sensing element; and

forming a transfer transistor on the semiconductor substrate.

11. The method of claim **10**, wherein forming the transfer transistor includes:

forming a gate oxide layer on the surface of the semiconductor substrate adjacent the photo-sensing element; and

forming a gate electrode on top of the gate oxide layer.

12. The method of claim **11**, wherein forming the gate electrode and forming the insulating film are performed in the same processing steps.

13. The method of claim **11**, wherein forming the gate electrode and forming the bottom electrode are performed in the same processing steps.

7

14. The method of claim 11, wherein forming the transfer transistor further includes forming a sensing node adjacent the gate oxide layer.

15. The method of claim 10, wherein forming the capacitor dielectric layer includes contacting the capacitor dielectric layer to the photo-sensing element.

16. The method of claim 10 further comprising forming a spacer adjacent a side of the insulating film and a side of the bottom electrode.

17. The method of claim 10 further comprising forming a spacer adjacent to a side of the transfer transistor.

18. The method of claim 10 further comprising forming an isolation region in the semiconductor substrate, wherein a portion of the capacitor structure is formed on top of the isolation region.

19. A method for manufacturing an image sensor, the method comprising:

forming a photo-sensing element in a semiconductor substrate;

forming a capacitor structure on the semiconductor substrate, wherein forming the capacitor structure includes:

forming an insulating film on a surface of the semiconductor substrate adjacent the photo-sensing element,

forming a bottom electrode on top of the insulating film,

forming a capacitor dielectric layer on top of the bottom electrode;

forming a top electrode on top of the capacitor dielectric layer; and

forming a conducting member on top of the top electrode and in contact with the photo-sensing element; and

forming a transfer transistor on the semiconductor substrate.

20. The method of claim 19, wherein forming the transfer transistor includes:

forming a gate oxide layer on another surface of the semiconductor substrate adjacent the photo-sensing element; and

forming a gate electrode on top of the gate oxide layer.

21. The method of claim 20, wherein forming the gate electrode and forming the insulating film are performed in the same processing steps.

22. The method of claim 20, wherein forming the gate electrode and forming the bottom electrode are performed in the same processing steps.

23. The method of claim 20, wherein forming the transfer transistor further includes forming a sensing node adjacent the gate oxide layer.

24. The method of claim 19, wherein forming the capacitor dielectric layer includes contacting the capacitor dielectric layer to the photo-sensing element.

25. The method of claim 19 further comprising forming a spacer adjacent a side of the insulating film and a side of the bottom electrode.

26. The method of claim 19 further comprising forming a spacer adjacent to a side of the transfer transistor.

27. The method of claim 19 further comprising forming an isolation region in the semiconductor substrate, wherein a portion of the capacitor structure is formed on top of the isolation region.

8

28. The method of claim 19, wherein:

a portion of the capacitor dielectric layer is formed over a portion of the photo-sensing element; and

a portion of the top electrode is formed over the portion of the capacitor dielectric layer that is formed over the portion of the photo-sensing element.

29. The method of claim 28, wherein the portion of the capacitor dielectric layer that is formed over the photo-sensing element is configured to insulate the top electrode from the photo-sensing element.

30. A method for manufacturing an image sensor, the method comprising:

forming a photo-sensing element in a semiconductor substrate;

forming a first dielectric layer on top of the semiconductor substrate;

forming a first conductive layer on top of the first dielectric layer;

patterning, substantially simultaneously, the first dielectric layer and the first conductive layer to form an insulating film and a bottom electrode of a capacitor structure and a gate dielectric and a gate electrode of a transfer transistor;

forming successively a second dielectric layer and a second conductive layer over the semiconductor substrate;

removing portions of the second conductive layer and the second dielectric layer that overlie the photoelectric element and overlie the gate dielectric to form a capacitor dielectric and a top electrode of the capacitor structure; and

forming a conductive member over a portion of the top electrode and a portion of the photo-sensing element; wherein the conductive member electrically couples the top electrode and the photo-sensing element.

31. The method of claim 30 further comprising implanting dopants of a first type into an exposed portion of the semiconductor substrate that is between the insulating film and the gate dielectric to form the photo-sensing element.

32. The method of claim 31, wherein the dopants are N⁺ dopants.

33. The method of claim 31 further comprising implanting dopants of a second type into a portion of the semiconductor substrate adjacent the gate electrode.

34. The method of claim 31, wherein the first and second types of dopants are the same type of dopant.

35. The method of claim 31, wherein the first and second types of dopants are N⁺ dopants.

36. The method of claim 30, wherein the gate dielectric is semiconductor oxide (SiO_x).

37. The method of claim 30, wherein the gate dielectric is tantalum oxide (Ta₂O₅).

38. The method of claim 30, wherein the insulating film and the gate dielectric are formed of the same type of material.

39. The method of claim 30, wherein the gate electrode and the bottom electrode are formed of the same type of material.

40. The method of claim 36, wherein the same type of material is doped polysilicon.